



The Contribution of Geodetic Fundamental Stations to Global Navigation Satellite Systems (GNSS)

Wolfgang Schlüter

Bundesamt für Kartographie und Geodäsie

Fundamental Station Wettzell, D-93444 Bad Kötzting



FGS
FESG



Content

- Geodetic space technics
 - Motivation for the observations
 - VLBI, SLR, GNSS- techniques
 - Accuracy
 - International collaboration
- Fundamental stations
 - Combination of the technique
 - Monitoring of local movements with GPS

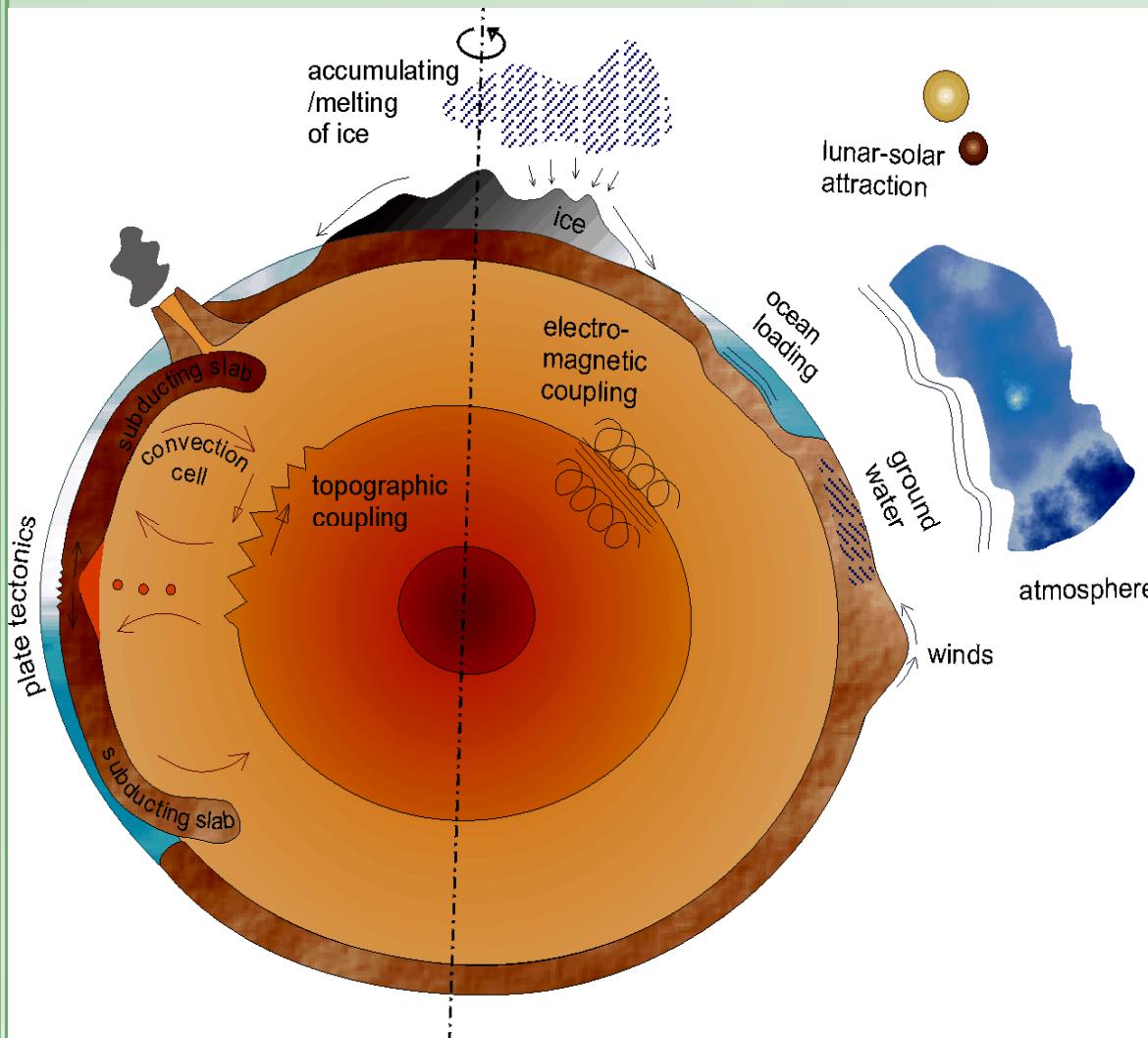


Evolution of Geodetic Space Techniques

- Satellite Space Techniques
 - 1960 Satellite Triangulation (first global network) ~10 m
 - 1970 Satellite Laser Ranging 1. Gen.
TRANSIT (Doppler) ~0.5 ... 1 m
 - 1980 Satellite Laser Ranging 3. Gen.
Very Long Baseline Interferometry (VLBI) ~3 cm
 - 1990 SLR/VLBI/GPS progress ~1 cm
 - 2000 Combination of Space Techniques ~3 mm
- Progress is based on technology developments of the last decades
 - Laser technology
 - Electronic ... signal processing
 - IT developments (VLBI: data recording, ...)
 - T&F (atomic clocks, frequency generator, time transfer)
 - Etc...
- Space Techniques employ time and timeintervall measurements



Changing Earth - Interactions



- **Mantle Convections**
 - Plate Motion
 - Volcanism
- **Sea level Rise**
 - Ice melting
 - Warming up
- **Tides (Moon, Sun, Planets)**
 - Ocean tides
 - Earth tides
- **Ocean**
 - Mass transport
 - Loading
- **Atmosphere/Wind**
 - Mass transport
 - Loading
- **Groundwater changes**

Variations in Positions, Gravity Field, Earth Rotation

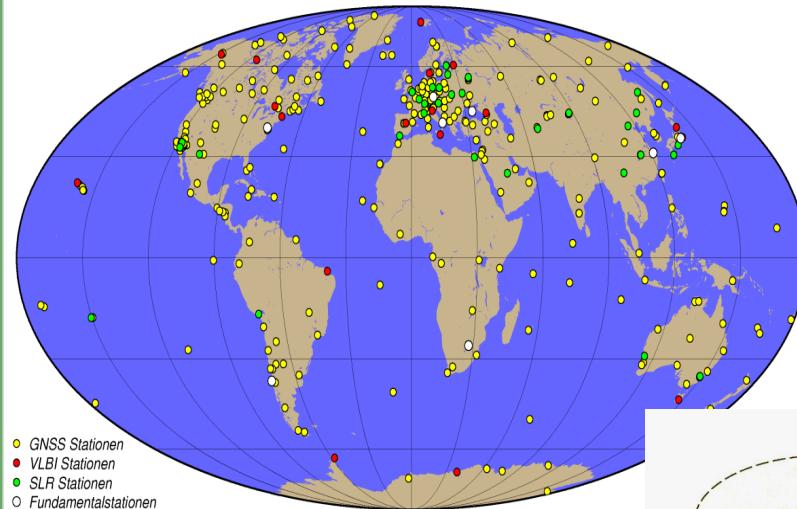


Continuous observations required

- Monitoring the variations
 - Improve the models (predictions)
 - Understanding of geophysical phenomena
 - Maintenance of global reference frames for positioning in space and on Earth
 - Quasar, Stars, Planets, Moon ...)
 - Space Crafts, Satellites,...
 - Geodesy
 - Geo-Information
 - Navigation
 -
- Fundamental for research in all geosciences and related disciplines



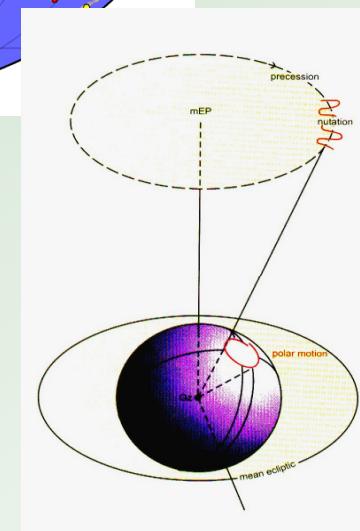
Global Reference Frames



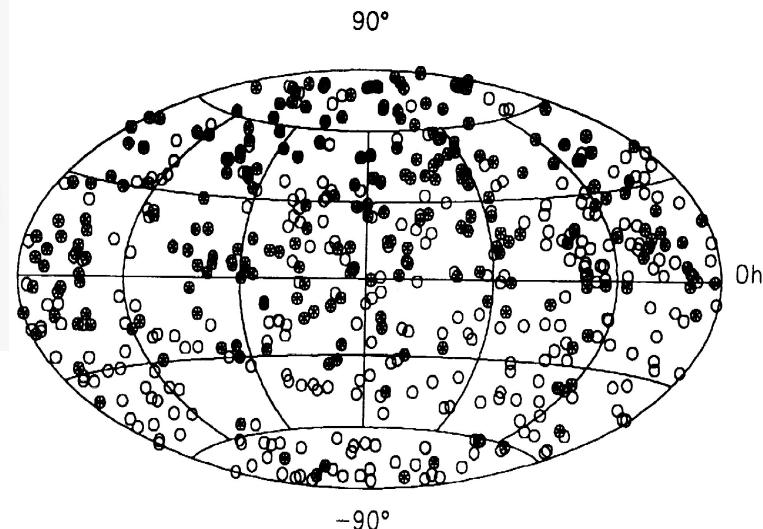
EOP: Earth Orientation Parameter

- Precession/Nutation
- Polar Motion
- UT1 - UTC

Earth Rotation combines ICRF and ITRF

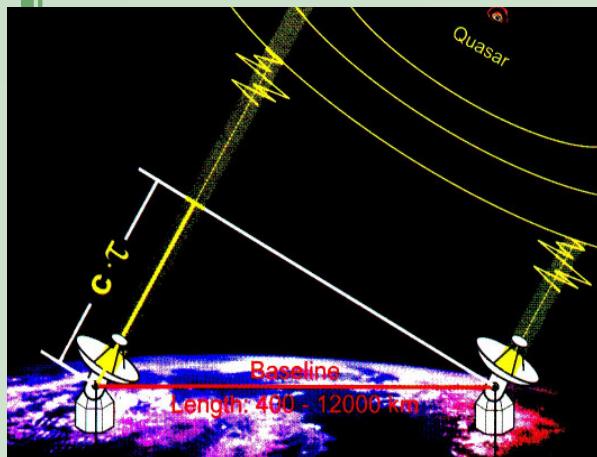


- **ITRF: International Terrestrial Reference Frame**
 - Position Coordinates
 - Velocity Vector
- **ICRF: International Celestial Reference Frame**
 - Quasar Positions

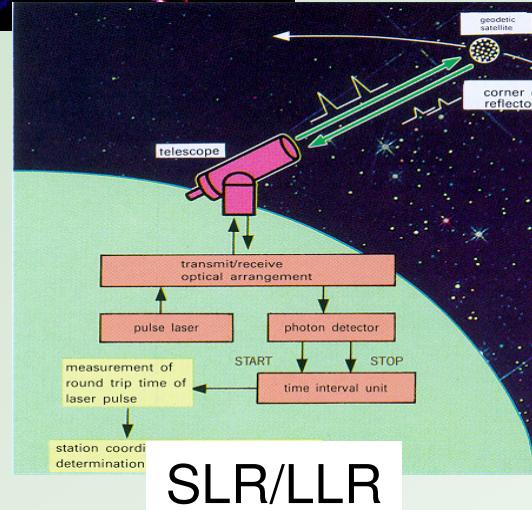




Geodetic Space Techniques

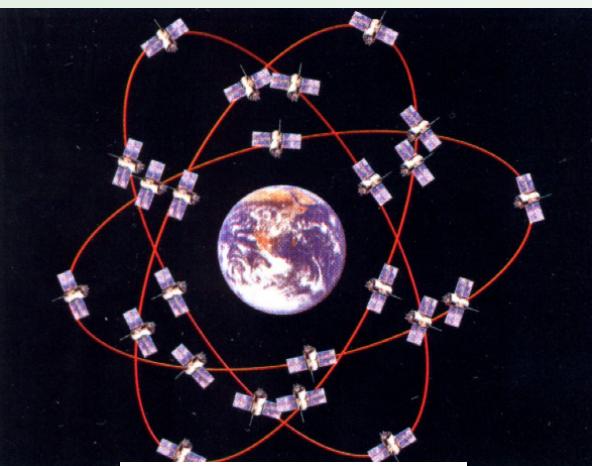


VLBI



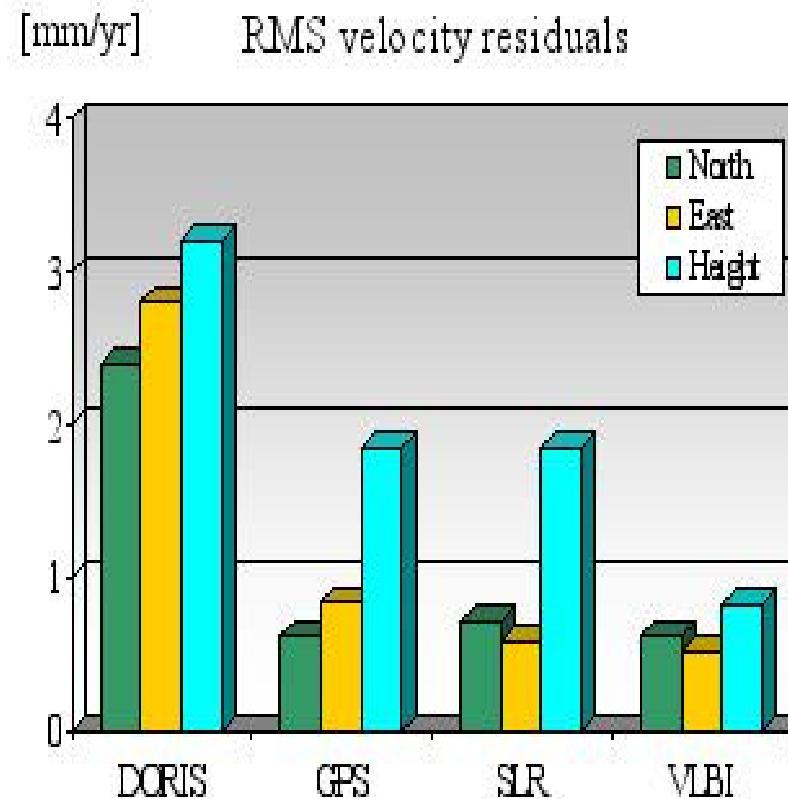
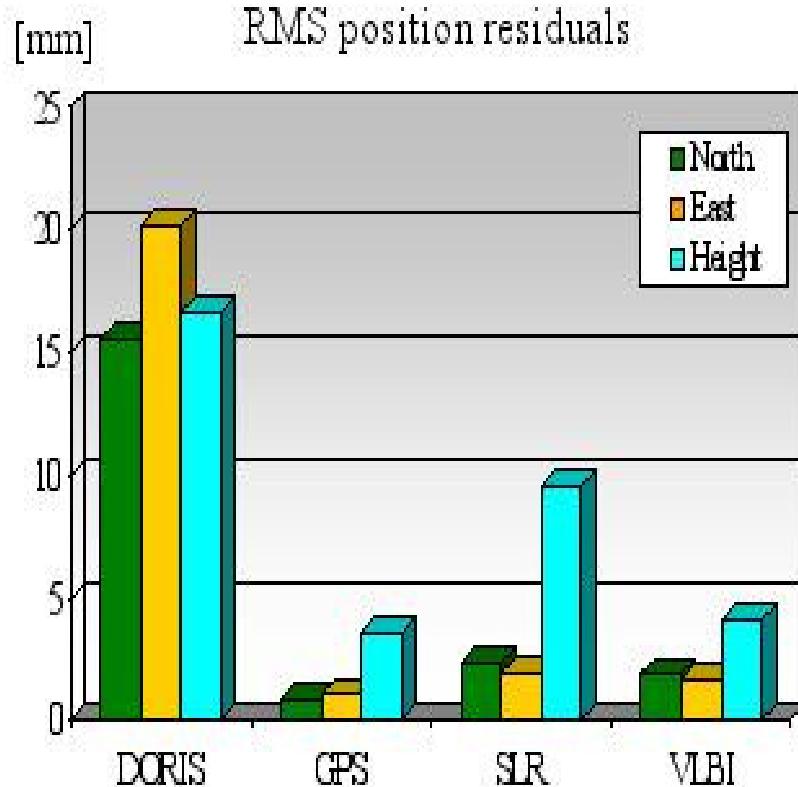
SLR/LLR

- **VLBI** (Very Long Baseline Interferometry)
- **SLR/LLR** Satellite/Lunar Laser Ranging
- **GNSS** (GPS, GLONASS, future: Galileo)
- **DORIS** (Doppler Orbitography and Radio Positioning Integrated by Satellite)



GNSS/GPS

RMS of Geodetic Space Techniques



(From a global TRF solution derived by DGFI, Munich)



International Cooperation

• IAG-, IAU Services

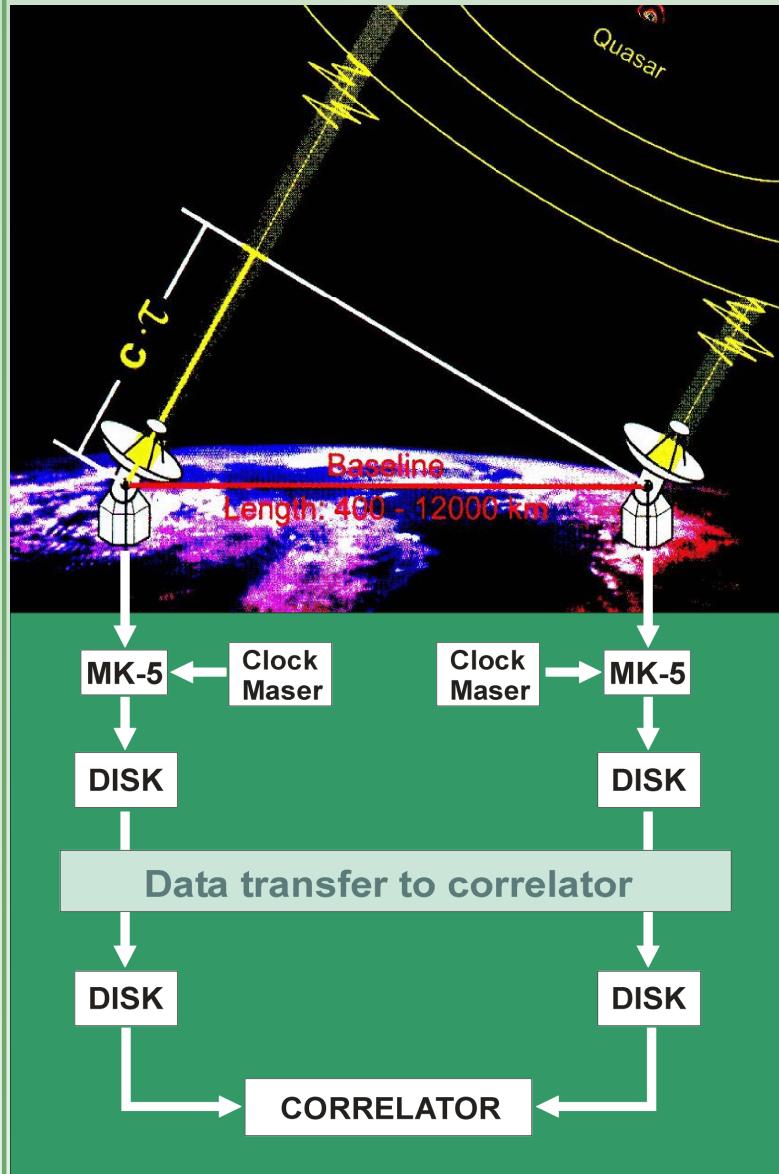
The maintenance of global reference frames is a very complex and a global task, which can only be solved on the international level. In the last years, international services were established by the individual techniques, in the frame of the International Association of Geodesy (IAG) or International Astronomical Union (IAU), in order to **coordinate the observations, the data flow, the analysis and the development of technology**. The services are the

- **International GNSS Service (IGS)**,
- **International Laser Ranging Service (ILRS)**,
- **International VLBI Service for Geodesy and Astrometry (IVS)**
- **International DORIS Service (IDS)** and the
Combination of the products by
- **International Earth Rotation and Reference Frame Service (IERS)**.

• IAG-PP: GGOS (Global Geodetic Observing System)

- **global reference frame, 10^{-9} precise**
- **consistent in geometrical and physical parameters**
- **consistent for decades!**

Principal of VLBI



- **Determination of the delay τ**
 - Position of Quasars are known (ICRF)
 - Simultaneous observations (of up to 400 quasars per 24h session)
 - Recording of Quasar signals in S/X Band
 - Precise clock information (H-Maser)
 - Data transfer to a correlator
 - τ (propagation delay) determination through correlation of the signals recorded at the stations
- **Products of VLBI**
 - Baseline-vector, positions (ITRF)
 - EOP,
 - Quasar positions (ICRF)
 - Tropospheric, ionospheric parameter,
 - Physical parameter (love numbers)
 - Clock parameter (need to be considered in the analysis)
 - Space vehicle orbits
- **Accuracy dependant on**
 - Signal resolution (BW, S/N):
data stream: < 2Gbps
 - Clock stability (H-Maser)

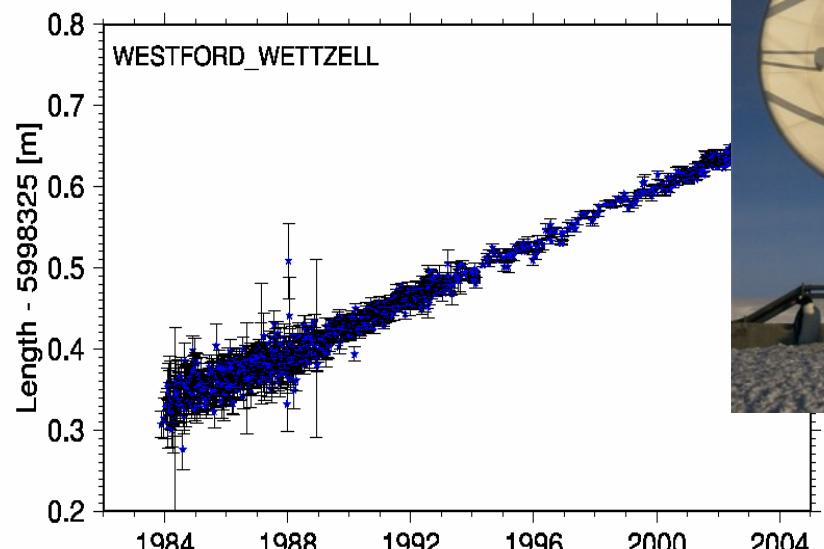


IVS - International VLBI Service for Geodesy and Astrometry



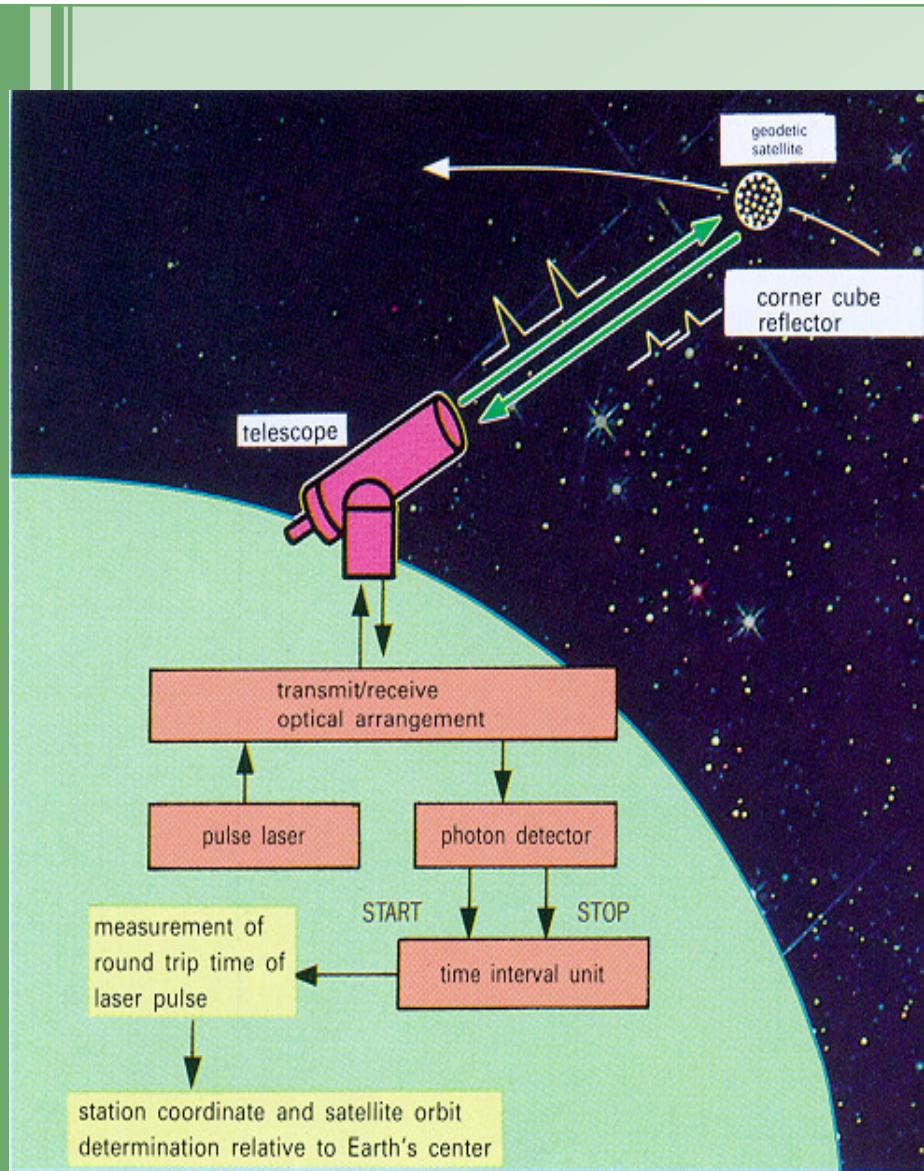


VLBI



- VLBI strength
 - Unique for CRF
 - Complete set EOP
 - Scale for TRF
- VLBI today
 - Digital Recorder
 - Data shipment, e-VLBI
 - S/X-Band
 - Delay $\tau \sim 30\text{ps}$
- VLBI 2010
 - New Instrumentation
 - Digital Recorders up to 2Gbps,
 - e-VLBI, Near Real Time
 - Continuous observations
 - 1...16GHz ...
 - Delay $\tau \sim 4\text{ps}$

Principal of SLR/LLR



- **Determination of the propagation delay**

- Transmitting short Laser pulse (pulse length: 30...100ps) generated by Nd:YAG-(1064/532nm) or TiSaPP-Laser (850/425nm)
- Precise tracking of the satellite with an optical telescope
- Corner cubes at the Satellite, to return the laser pulse
- Detection of the returns (Single Photon level)
- Event timer to measure the propagation delay (1mm ~ 6ps two-way))
- Recording the events with respect to UTC(?)
- Calibration (internal and external)

- **Products**

- precise satellite orbits
- Geo-center, contributions to Gravity field
- Positions and velocities
- Polar motion
- (Time transfer)

- **Accuracy dependant on**

- Event timer resolution
- Pulse lengths, single photon level
- Calibration
- Statistic (normal points)
-



ILRS- Global Network





SLR / LLR



WLRS: 75cm Telescope



TIGO-SLR



LAGEOS 1



Reflector on the Moon
Apollo 15

– Satellites

- LAGEOS 1+2
- Starlette
- Stella
- ETALON1+2
- **GPS 35+36**
- **6 GLONASS**
- ERS 2
- ENVISAT
- AJISAI
- BEACON
- TOPEX
- GRACE
- **GALILEO (GIOVE A)**
- Etc.

– Moon

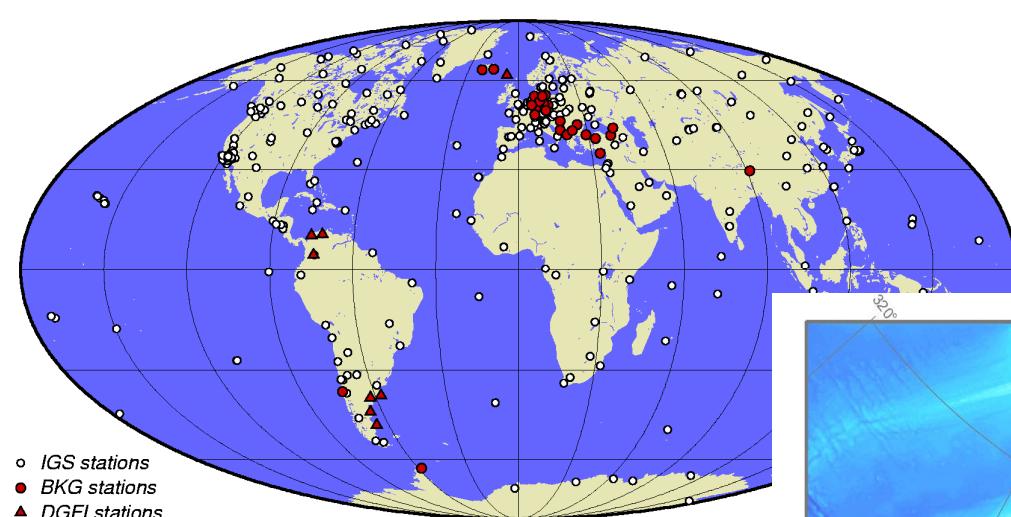
- NASA Apollo Missions
- Russian Missions

– Future developments

- kHz- repetition rate
- Two wavelengths
- Laser transponders



GPS/GLONASS - FSW



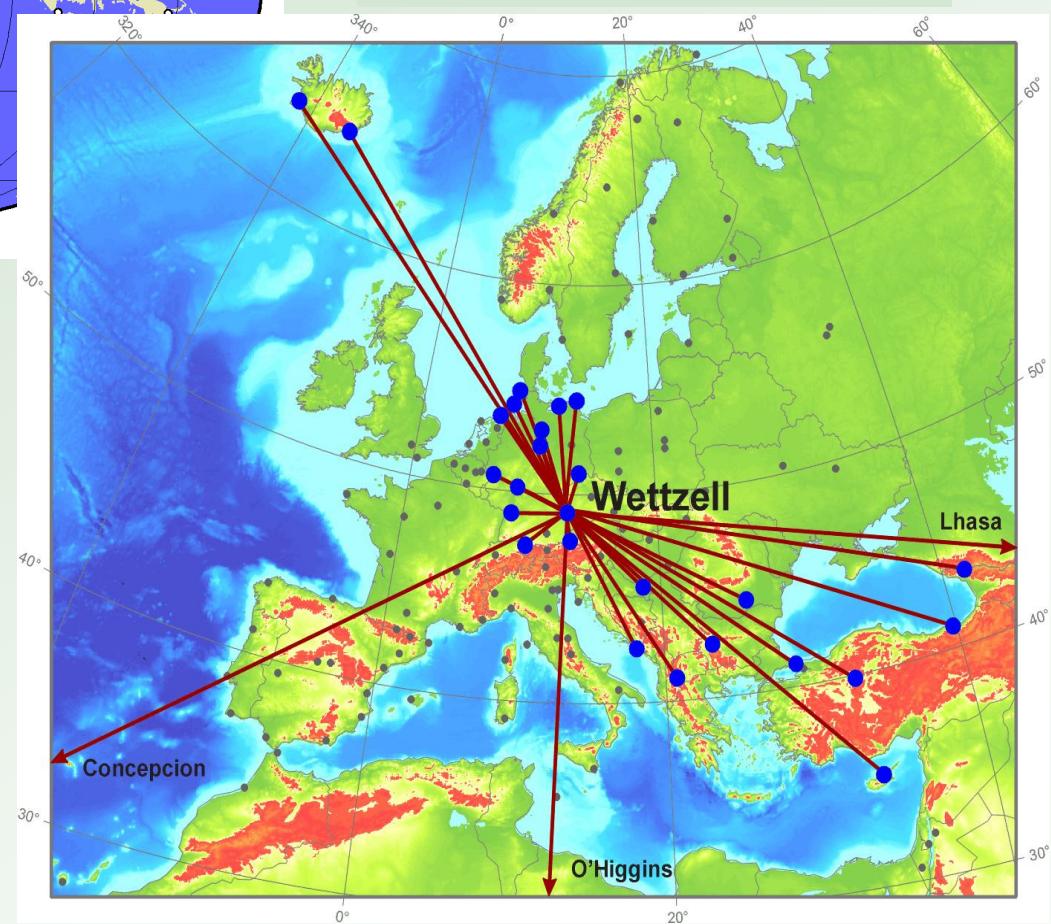
IGS

Contribution of

- 24h data files
- 1h data files
- RT
- Meteo data

FSW operation center for

- IGS
- EUREF
- GREF





Fundamental Stations (Wettzell and TIGO)



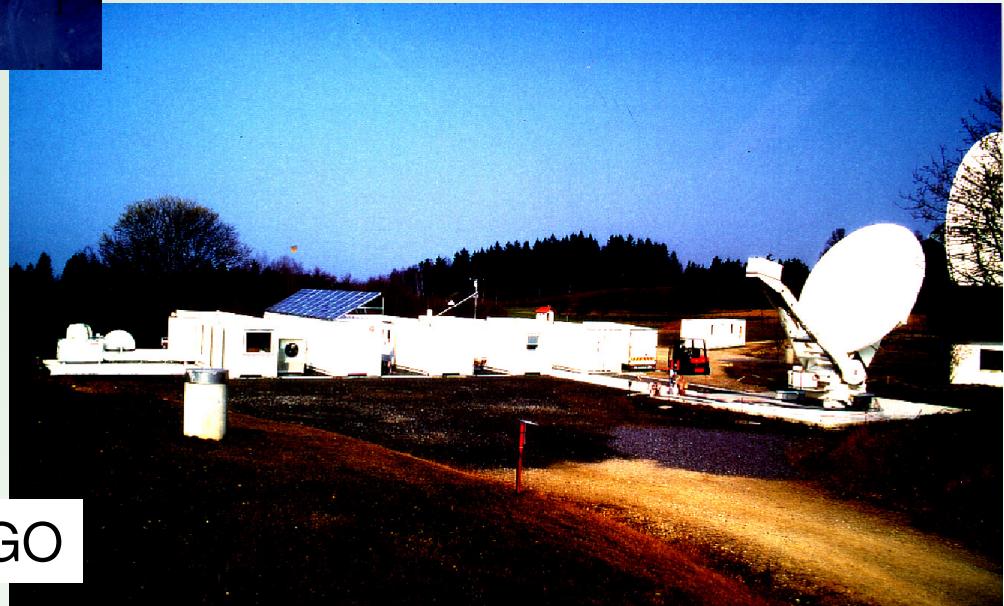
FS-Wettzell

- Matera, Italy
- Shanghai, China
- Keystone, Japan
- Hartebeesthoek,S.- Africa
- Greenbelt, USA

Collocation of geodetic space techniques

- Control, Comparison
- Complementary
- Long term observations
- Unification of the products
- Common influence of phenomena
- Common instrumentation, e.g.T&F ...

Local ties, local survey



TIGO



Tasks of Fundamental Station (e. g. FSW)

- Contribution of long, redundant time series of observations
 - Geodetic Space Techniques
 - Very Long Baseline Interferometry (VLBI)
 - Laser Ranging to satellites and to the Moon (SLR/LLR)
 - Microwave technology (GPS, GLONASS, DORIS, Galileo)
 - In situ observations
 - T&F,
 - Gravimetry,
 - Meteorology, WVR
 - Seismic,
 - local survey,
 - footprint observations.
- Participation in international observing programs
 - IAG-, IAU services
 - Research and development



Time and Frequency

Cs-Normal



T&F-Messplatz



H-Maser

- Epoch
 - 10ns
- Frequency
 - Absolute 10^{-13}
 - Relative 5×10^{-16}
- Hardware
 - 5 Cs-Standards
 - 3 H-Maser
 - GPS-time receivers
- UTC(IFAG)



GGOS: Present and Future Combination

Parameter space for a rigorous combination:

Parameter Type	VLBI	GPS/ GLON.	DORIS/ PRARE	SLR	LLR	Alti- metry
Quasar Coord. (ICRF)	X					Earth Rotation
Nutation	X	(X)		(X)	X	
Polar Motion	X	X	X	X	X	
UT1	X					
Length of Day (LOD)		X	X	X	X	Gravity Field
Coord.+Veloc.(ITRF)	X	X	X	X	X	
Geocenter		X	X	X		
Gravity Field		X	X	X	(X)	
Orbits		X	X	X	X	Atmosphere
LEO Orbits		X	X	X		
Ionosphere	X	X	X			
Troposphere	X	X	X			Time/Freq.; Clocks
Time/Freq.; Clocks	X	X		X		

ICRF

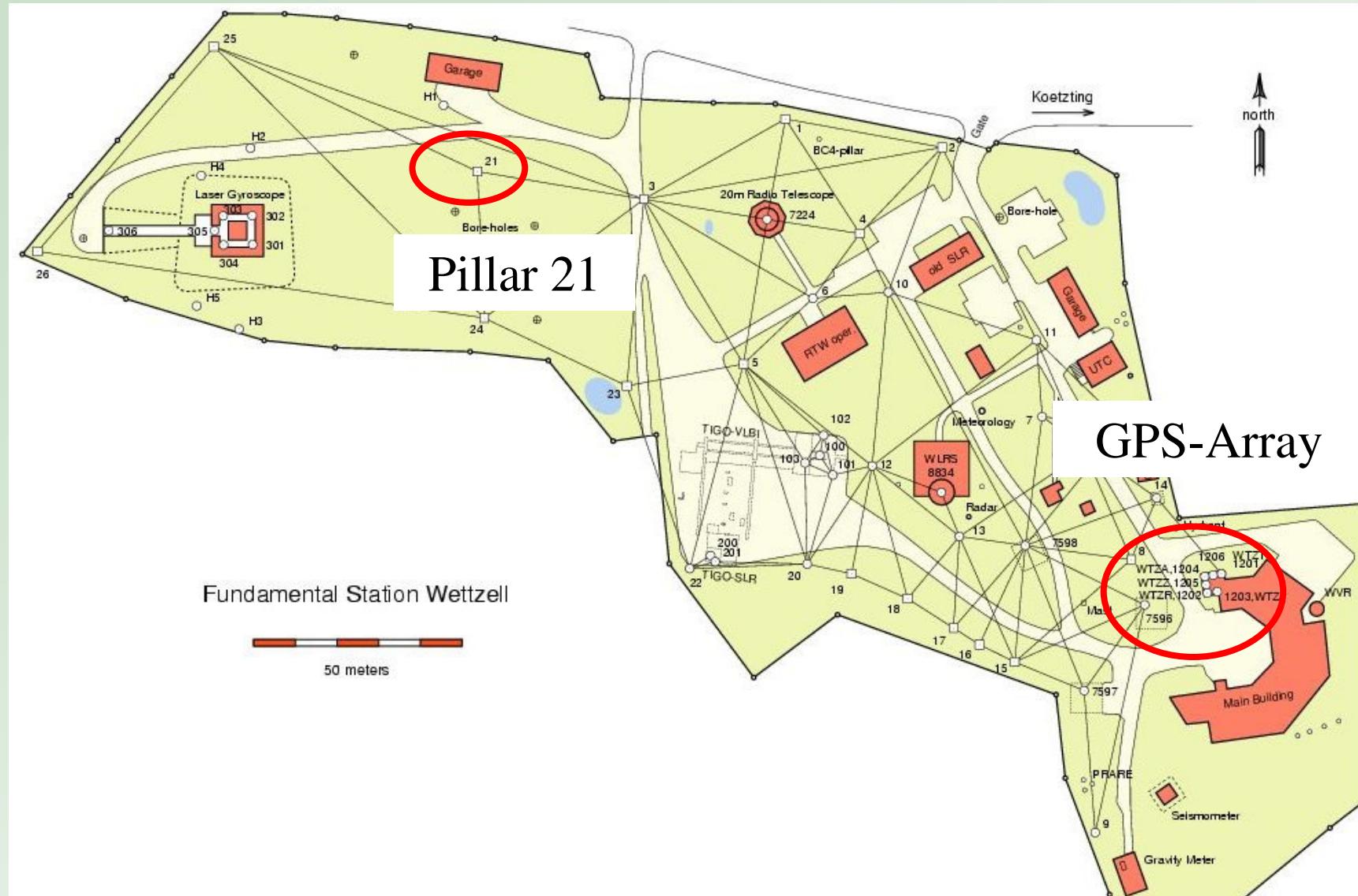
ITRF Atmosphere

Earth Rotation

Gravity Field

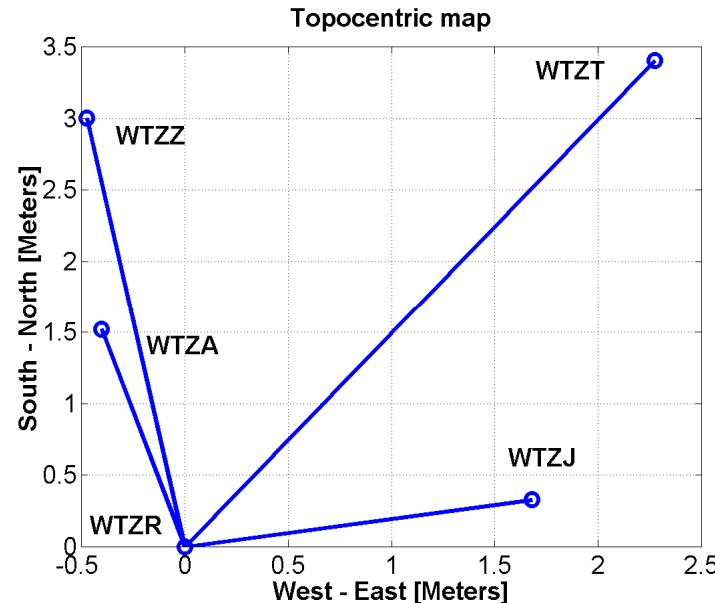


Local Survey Network





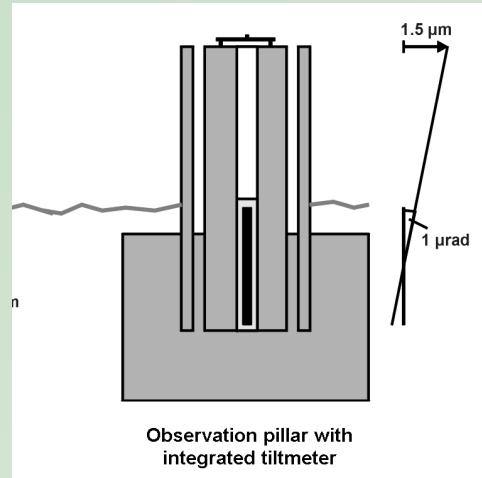
GPS Antenna Array



- GPS Array
 - WTZR
 - Turbo Rogue ACT
 - WTZA
 - Ashtech Z12T
 - WTZZ
 - Javad (GPS/GLONASS)
 - WTZT
 - Trimble 4000SSI
 - WTZJ
 - Javad (Real Time)
- WEB Cam
 - Taking pictures (clouds, snow, sunshine)



Pillar 21

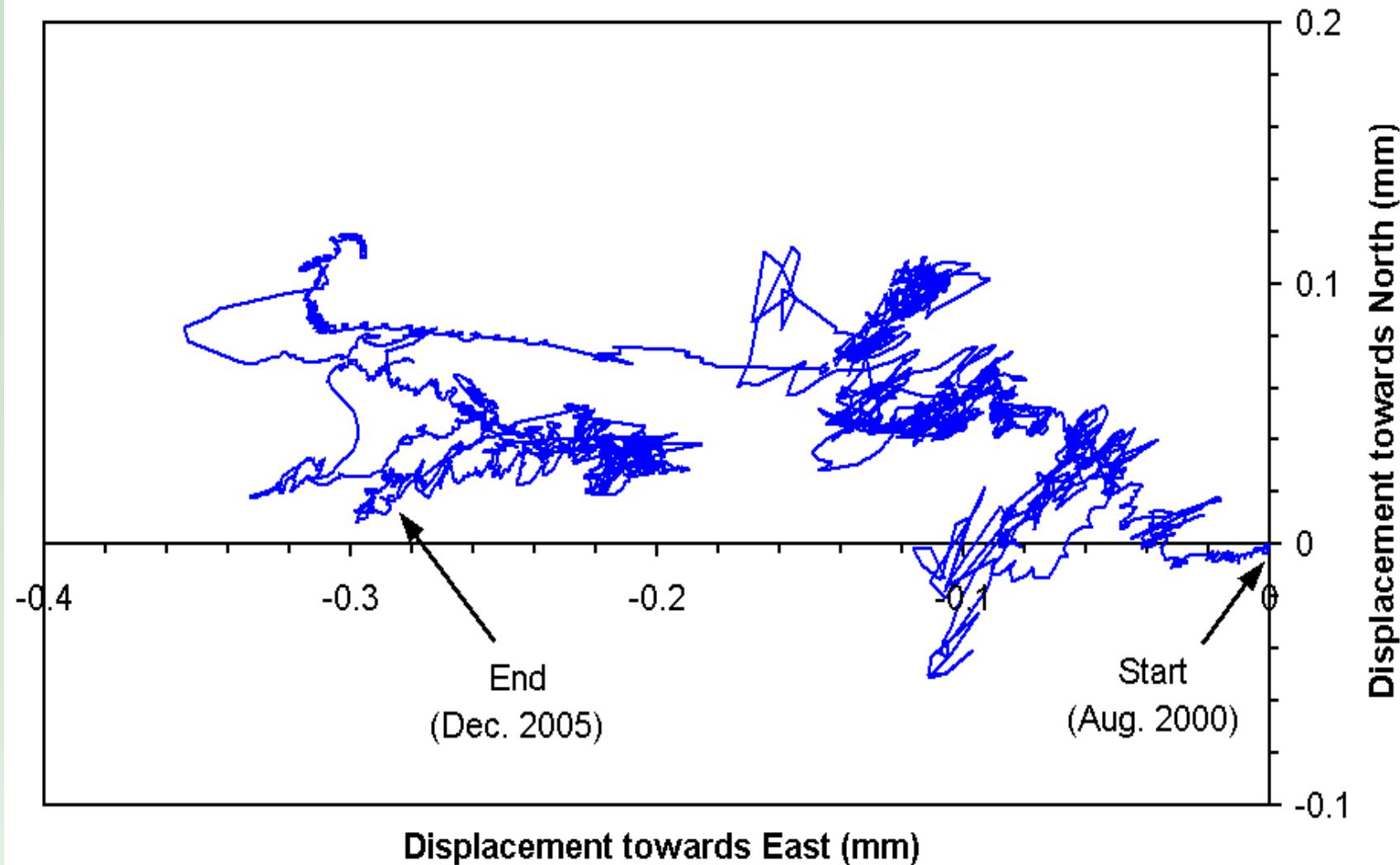


- Survey Pillar with an integrated AGI 722 borehole tiltmeter, resolution <100nrad)
- GPS Receiver Ashtech Z12 for continuous observations



Pillar 21 - Stability

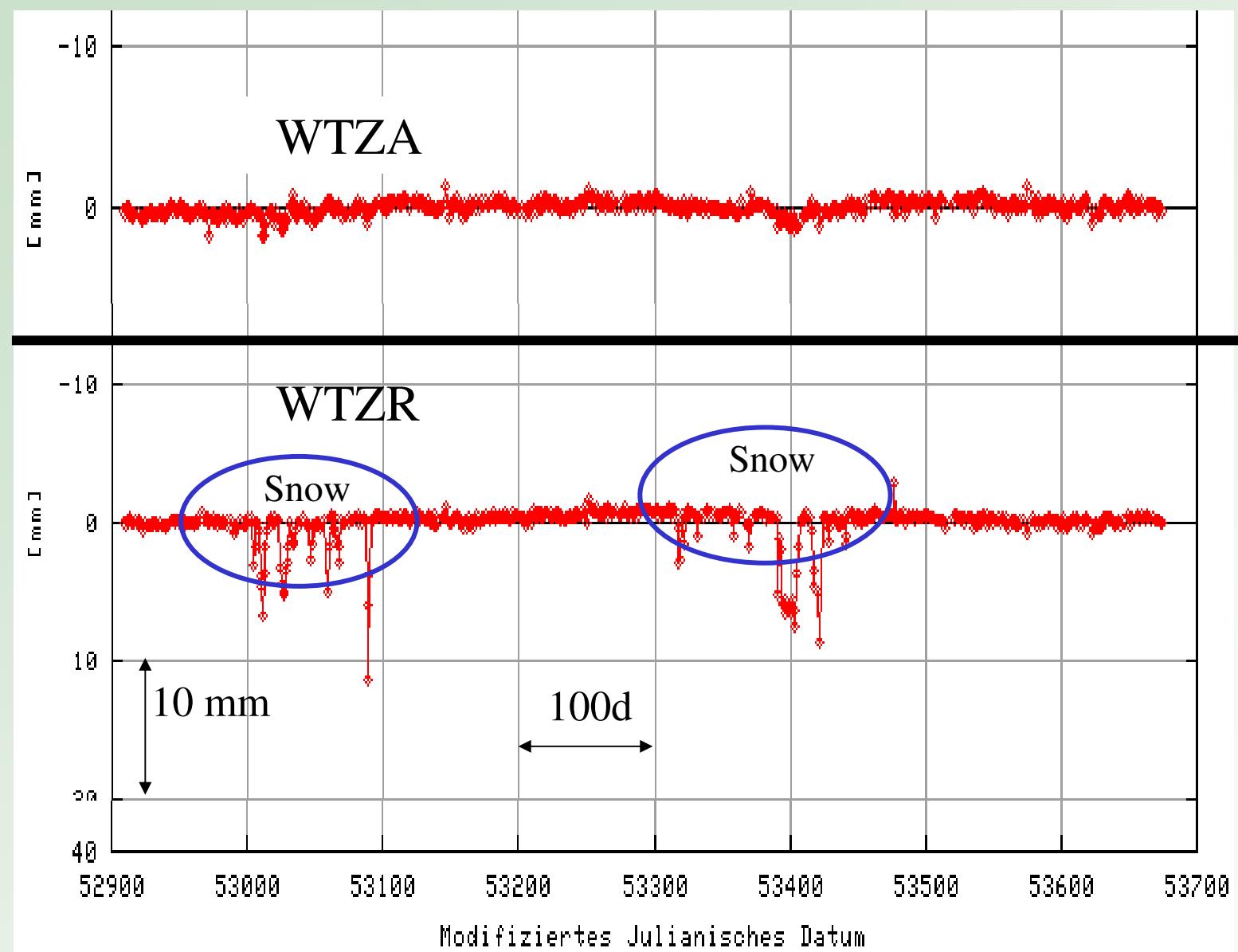
Trace of motion of pillar top due to tilt, pillar 21





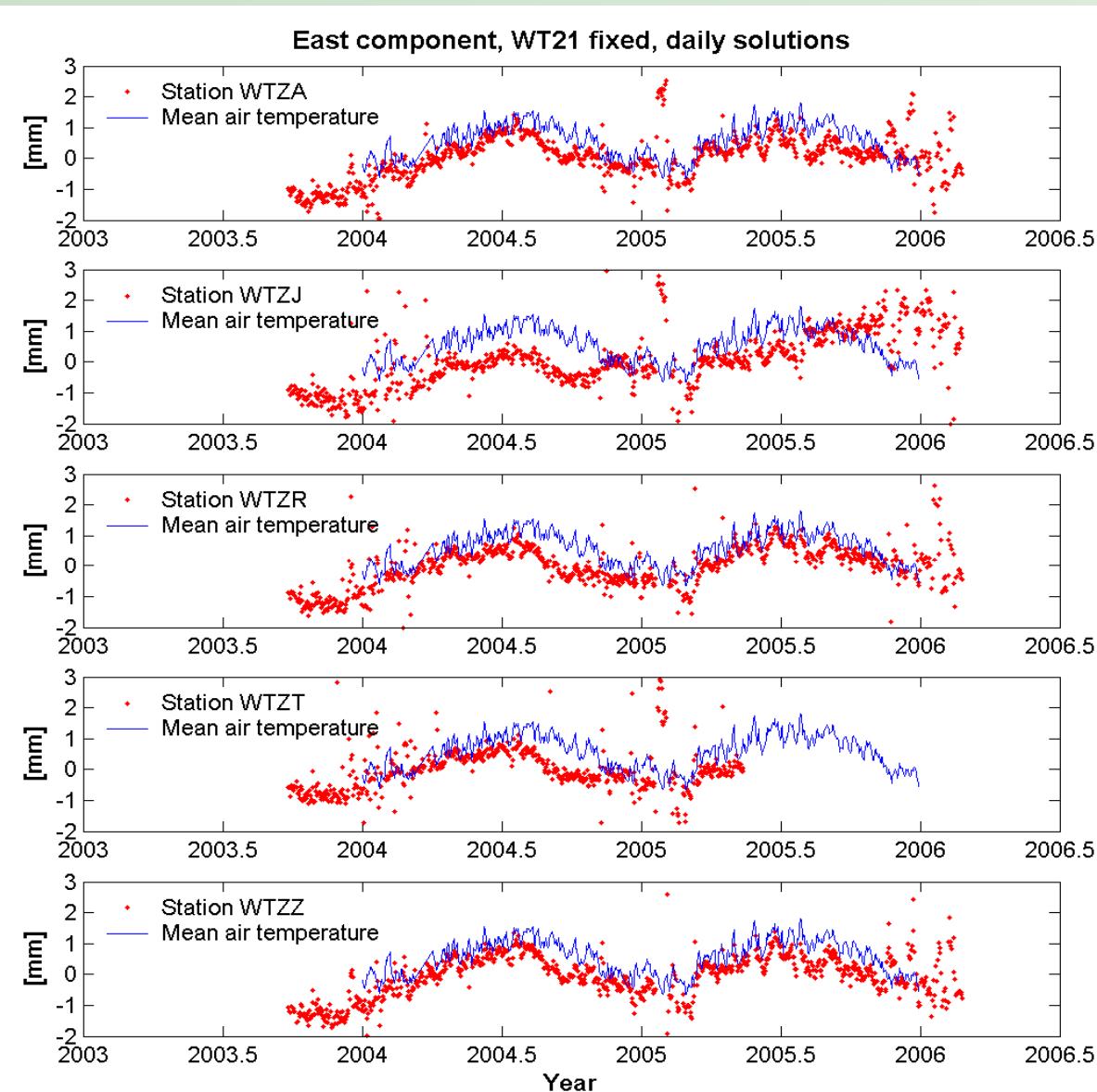
Residuals in Height of GPS Array

WTZA and WTZR with reference to Pillar 21





Example: East Component of WTZ# and the Correlation with air temperatur





Conclusion

- Fundamental Station - key words:
 - complementary
 - redundancy
 - Permanency
- Each technique has common and different sensitivities, all information is needed
- Fundamental to
 - verify the products, control
 - make best use of the techniques characteristics and sensitivity by combination
 - investigate systematic errors
- Combination of the techniques will give the best results



Thank you!